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MEASURING SLEEP BY WRIST ACTIGRAPH

ANNUAL REPORT

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Current results now allow us to specify design criteria for a miniaturized wrist-mounted activity monitor suitable for field or combat use.

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SUMMARY

A convenient method of monitoring personnel sleep and activity in field conditions is needed to promote medical planning for modern combat.

In the period from April 1980-March 1981, we have programmed, tested, and begun evaluations of a wearable digital activity system, and we have refined a computer process for recognizing sleep from this system. Together, these efforts enable us to collect data from freely ambulatory subjects which can be scored automatically for sleep/wake with accuracy comparable to EEG scoring. The system is ready for miniaturization leading to field use.

Our microprocessor-based digital activity monitor was built to our specifications, and we added external activity and illumination transducers. Actual data collection was implemented and 25 records totalling over 27,000 minutes have been obtained as of March, 1981. Fourteen records (12,739 minutes) collected with the digital monitor were scored retrospectively with 93.6% agreement with EEG sleep/wake scoring. Research is continuing to further increase the accuracy of the sleep recognition algorithm. Since the errors that occur include both mis-scoring sleep as wake and vice versa, they tend to cancel. Correlations between sleep durations scored from activity data and from EEG records were $r=.9760$ for digital monitor data.

Current results now allow us to specify design criteria for a miniaturized wrist-mounted activity monitor suitable for field or combat use.

FORWORD

For the protection of human subjects the investigator has adhered to policies of applicable Federal Law 45CFR46.

INTRODUCTION

Sleep loss and combat fatigue are increasing concerns for the modern army. A future war is likely to be extremely brief and intense, with victory and defeat determined in a few days or weeks. Soldiers using technically sophisticated modern weaponry will have little time for sleep, and plans must be made to enable personnel to perform effectively throughout the duration of a combat of unprecedented intensity. American troops may have to enter combat immediately after airlift to remote parts of the world, and plans must be developed to minimize the effects of jet-lag on personnel performance.

Military medicine therefore needs a practical method of quantifying sleep both to design personnel strategies and for potential monitoring of troops in actual field deployments.

Traditional physiologic methods for monitoring sleep through EEG-EOG-EMG recordings are completely impractical in actual or simulated combat settings, and subjective monitoring has been shown to be unreliable (1). In addition, both physiologic measures and observational methods for measuring sleep are costly, and considerable time is necessary to quantify sleep by scoring polygraph records.

We are developing a wrist activity monitoring technique as a solution to these problems.

Employing Delgado's (2) telemetric activity recording device, Kupfer et al (3) and Foster et al (4,5) described the use of activity data for quantifying sleep and assessing sleep quality in humans. Encouraged by the high correlations between EEG and actigraphic estimates of sleep -- 0.84 and 0.88 in two separate studies (6,7) -- Kripke et al (8) developed a system in which a piezo-ceramic activity transducer worn on a watchband recorded wrist activity onto a Medilog cassette tape recorder worn on a belt. With this transducer, Kripke et al (8) obtained a correlation of 0.98 between sleep duration determined from wrist activity and the EEG in five subjects.

A more exhaustive study of 63 nights of normal subjects and 39 nights in hospital patients with various sleep disorders was conducted under the first year of our contract (DAMD-17-78-C-8040, 1978-1979). All-night recordings of wrist activity, EEG, EMG and EOG were collected simultaneously on a 4-channel cassette. Each minute was scored as either sleep or wake by one rater using only activity data, and a second rater using only EEG-EOG-EMG data. The raters agreed on 94.5% of the minutes (96.3% for non-patients). Estimates of each subject's total sleep time with the two methods were correlated 0.89 (0.95 for non-patients). These results indicate that the wrist actigraphic analog recording contains sufficient information to produce a highly reliable scoring of sleep.

Having shown that sleep can be identified from activity data, we proposed in 1979 to design a 2-part sleep monitoring system. A digital activity monitor, consisting of an activity transducer, microprocessor and digital memory, would be worn on the wrist. A portable readout device, also microprocessor based, would read and reset the monitors, then interpret their data and generate a sleep report.

To realize this design, a first priority was to establish the optimal design, orientation and placement for the activity transducer. We found the piezo-ceramic transducer used in our previous research to be more sensitive than other available transducers and to be adequately omnidirectional. We also found the wrists to be more active than an ankle or the head, and therefore a better site for locating a transducer. The choice of wrists does not seem crucial, but the non-dominant wrist seems slightly superior (e.g., the left wrist).

Having established optimal transducer design characteristics, we turned our attention to digitizing, preprocessing and storing activity data. As reported in our 1979-1980 report, we found that digitizing at 240 Hz and summing every four digital conversions cancelled 60 Hz noise which sometimes contaminates activity recordings. We also found that a preprocessing algorithm which emphasized changes in activity level provided the best data for automatic sleep recognition. Our 1979-1980 report described our approach to empirically developing an algorithm to recognize sleep from digitized activity data. The further refinement of that approach, and its implementation in a wearable system will be described below.

FURTHER PROGRAM DEVELOPMENTS

Method

Data were obtained from subjects participating in studies involving EEG recording during both wake and sleep. A wrist activity transducer signal was sampled during both wake and sleep. The wrist activity transducer signal was sampled by the analog-to-digital (A/D) converter of our laboratory computer system at a conversion rate of 240 Hz. The analog data was digitized and stored as described in our 1979-1980 report, but only the optimal preprocessing transformation selected in that report was used in data analysis. A total of 20 records (13,488 minutes) were analyzed.

Development of the sleep recognition algorithm began with expressions incorporating a weighted sum of combinations of the digital data with potential for discriminating sleep from wake. Specifically, the expression took the form:

$$D = S \times (W_1 T_1 + W_2 T_2 + W_3 T_3 + W_4 T_4 + W_5 T_5 + W_6 T_6)$$

where S was a scale factor, W's were weights, and:

T_1 = the sum of the digital activity values for all 30 2-second data epochs in a minute,

T_2 = the activity value for the single most active epoch,

T_3 = the sum of the activity values in the two most active epochs separated by at least 30 seconds,

T_4 = the sum of the activity values in the most active 8 epochs.

Terms T_5 and T_6 were themselves weighted sums of term T_1 over the preceding 4 and following 2 minutes:

$$T_5 = W_{51} T_{1,i-1} + W_{52} T_{1,i-2} + W_{53} T_{1,i-3} + W_{54} T_{1,i-4}$$

$$T_6 = W_{61} T_{1,i+1} + W_{62} T_{1,i+2}$$

where $T_{1,i-1}$ is the maximal epoch value for the preceding minute, $T_{1,i+1}$ for the following minute, etc.

A minute was scored 'wake' if $D \geq 1.0$. For each given combination of weights, a range of weights (W) and scale factors (S) was substituted into the above expression for each minute, and the resulting sleep/wake score for all minutes. The proportion of minutes for which the automatic score and EEG score agreed was then computed for each scale value, and the maximum agreement served as a retrospective measure of the effectiveness of the weighting. The computer program (Appendix 1) varied the weighting of one term at a time, and searched for the combination of weights which produced the highest agreement.

As preliminary results became available, it became apparent that better agreement was obtained when $W_1 = W_3 = W_4 = 0$, i.e., the maximal epoch value in each minute was the best discriminator of sleep and wake. This unexpected result was extremely fortunate, since it permitted reducing the data required for sleep scoring by an order of magnitude compared to our prior expectation. We had expected that all 2-second epoch values for each minute would have to be stored.

Accordingly, a second expression was developed:

$$D = S \times (W_1 T_{2,i-4} + W_2 T_{2,i-3} + W_3 T_{2,i-2} + W_4 T_{2,i-1} + W_5 T_{2,i} + W_6 T_{2,i+1} + W_7 T_{2,i+2})$$

where W's represent weights and $T_{2,i}$ represents the maximal epoch value (T_2 in the previous expression) for the current minute, $T_{2,i-1}$ for the previous minute, $T_{2,i+1}$ for the succeeding minute, etc. Again, the computer varied the weighting and compared the resulting sleep/wake score with the EEG score until maximal agreement was obtained.

Seventeen of the 20 records were used in the algorithm development phase described above. The remaining three records were scored prospectively, i.e. each of the three records was scored individually with the single weighting and scale factor found optimal in the development phase. In this test, the laboratory computer simulated the actual deployment of an automatic sleep scoring system, with the results compared to EEG scoring.

Results

The optimal algorithm reached after analysis of the 17 records was:

$$D = .025 \times (.15T_{2,i-4} + .15T_{2,i-3} + .15T_{2,i-2} + .08T_{2,i-1} + .21T_{2,i} + .12T_{2,i+1} + .13T_{2,i+2})$$

where $T_{2,i}$ represents the maximal epoch value in minute i , etc. If $D \geq 1.0$, the minute was scored 'wake', otherwise 'sleep'. The best retrospective agreement between sleep/wake scored automatically with this algorithm and scoring from

EEG records was 94.46% -- that is, 94.46% of all minutes from the 17 subjects were in agreement with the 'true' sleep/wake score. Agreement scores and the proportion of the record scored as sleep by EEG and by the automatic algorithm for each individual subject are shown in Table 1. Again, it should be noted that this is retrospective agreement, the data for these individuals already having been used to select the optimal algorithm.

The ability of this algorithm to score sleep/wake prospectively was tested with the remaining three records. For these records, only the single expression found optimal in the algorithm development phase was chosen prospectively to automatically score sleep/wake. Overall agreement of these three records with EEG scoring was 96.02%. Agreement and the proportion of each individual record scored sleep by both procedures is also shown in Table 1.

In order to understand the remaining shortcomings of the automatic sleep/wake scoring algorithm, data for all minutes mis-scored were listed and compared with the paper record. In general, the conditional probability of mis-scoring wake as sleep was higher (.062) than mis-scoring sleep as wake (.039). A major reason for the higher probability of mis-scoring wake was the tendency of some subjects to lie in bed quietly for up to half an hour before falling asleep, while generating alpha-frequency EEG. On the other hand, while most examples of mis-scoring sleep were due to the presence of activity during sleep, the source of error in these cases was not so much a failure of the actigraphic scoring concept as a problem with the 1-minute scoring epoch chosen for this study. Many of the 'activity during sleep' errors actually represented arousals, but the EEG record showed that the period of wakefulness was less than the one-half minute required to score a 1-minute epoch as wake.

Since mis-scoring occurred in both directions, the estimates of total sleep duration were better than might be inferred from the minute-by-minute agreement figures. The correlation coefficient between the proportion of the record scored as sleep automatically from activity and as hand-scored from EEG were $r=0.9889$ (for the 17 records scored retrospectively) and $r=0.9982$ (for the 3 prospective records). Thus, the automatic scoring represents the relative duration of sleep extremely accurately. Since sleep duration is the dimension of sleep most crucial to sustaining performance, we feel that the automatic sleep recognition procedure described here represents a very effective scoring technique.

A further test conducted with these data sought to determine the resolution in the stored data necessary to achieve these levels of accuracy. The digital activity value was stored on disk as a 16-bit word, i.e. a number in the range of 0-32767. To investigate the resolution requirement, the sleep recognition program was repeated with the same data, but the resolution was reduced by dividing by powers of 2 and truncating. There was no decrease in agreement with 4-bit data (0-15) and a decrease of only 0.1% with 3-bit data (0-7). This surprising result is important, since it means that more data can be stored in a given memory capacity of the wearable activity monitor, providing appropriate scale factors are chosen.

TESTING THE DIGITAL ACTIVITY MONITOR

In our original proposal to produce a wearable digital activity monitor, we suggested a design in which the signal from a piezo-ceramic activity transducer would be entered through an analog-to-digital converter into an IM6100 microprocessor, and the processed activity values stored in random-access memory. All electronic components of this proposed system would be CMOS for minimal power consumption.

As noted in our 1979-1980 Annual Report, we found that these components could be assembled by the Vitalog Corporation*. After extensive discussions with Vitalog, we ordered a prototype monitor consisting of an IM6100 microprocessor, IM6001 Parallel Interface Element, 6K x 12 RAM memory, 512 word EPROM memory, 8-channel A/D converter, crystal clock and an LED indicator light. The unit is powered by rechargeable 5.6 volt batteries. It is enclosed in a 15 cm x 9 cm x 5½ cm plastic case. Vitalog also provided an interface between the monitor and our Apple microcomputer.

After receiving the monitor, we designed and built an external transducer incorporating a piezo-ceramic element, a photocell, a battery and amplification circuitry necessary to match the A/D input requirements. (The photocell was included to permit an objective measure of "lights out" and "lights on" and potentially to investigate sleep onset latency.) This external transducer, 7 cm x 4 cm x 2 cm, is worn on a wrist band like a watch. It is attached to the monitor by a cable. A schematic diagram of the transducer circuitry is presented as Figure 1.

Having assembled and tested the monitor system, we began by investigating its technical capabilities. One very important technical consideration was the useful life of the battery charge, since this limits the duration of a recording session. Battery drain was found to be 3.4 mA when the processor was halted and 8.5 mA when running. Since in most applications the processor is idling much of the time, a third state (WAIT) can be entered which keeps the processor running, but not executing instructions, at a drain of about 5.2 mA. The battery life was found to be 70 hours at 8.5 mA (running continuously) and 180 hours at 5.2 mA (running with WAIT). We subsequently devised a system for changing batteries without disturbing the recording, removing this limit to recording duration. We also investigated the accuracy of the crystal clock, and found that it lost 1.2 seconds each hour, well within acceptable limits. While considerable improvement in battery life can probably be obtained in any future model, the Vitalog system already demonstrates the feasibility of powering a microprocessor-based wrist activity monitor.

The majority of our effort in preparing the monitor system for use has been in development of a monitor program to direct the collection and storage of activity data. The algorithms for converting the continuous analog signal from the activity transducer to a value representing activity for each minute were equivalent to those discussed above. The monitor program that was ultimately developed, tested, and used to collect digital activity records digitized the signal from the transducer at 240 Hz, and 4 consecutive values were summed to provide a measure of activity free of 60 Hz noise. The sum was then transformed

*Vitalog Corporation, 1056 California Avenue, Palo Alto, CA 94306.

to a difference score, and 120 such scores summed to produce an activity value for each 2-second data epoch. Every minute, the greatest 2-second activity value in that minute was stored. A voltage indicating the illumination level of the photocell was also digitized and stored each minute and a time code was signaled through the LED. The monitor program (Appendix 2) fills 448 memory locations, leaving 5696 locations available for data storage. This allows us to store two 12-bit data words (activity and illumination) each minute for 47 hours and 28 minutes. Since 4-bit resolution would be adequate, up to 6 times this duration or about 12 days sleep data could be stored were the illumination data sacrificed and battery changes feasible.

For test recordings, where it is necessary to compare digital activity records with EEG recordings, the LED was coupled through a receiving photocell to the polygraph to provide a time reference each minute on the polygraph record. The EEG recordings were scored, and both EEG and activity monitor scores were transferred to our laboratory computer system. To date, 25 laboratory recordings totalling over 27,000 minutes have been collected, and 14 have been fully analyzed retrospectively. Results are presented in Table 2. Retrospective agreement of these 14 records (12,739 minutes) is 93.6% with EEG scoring. The correlation coefficient between the proportion of each record scored as sleep by the two techniques is $r=.9760$.

In the final months of our 1980-1981 contract year, we plan to analyze a series of activity-monitored nights with prospective scoring to complete validation of our sleep scoring methodology. In addition, we will prepare a complete technical specification of the methodology from which a microminiaturized monitor wearable entirely on the wrist could be built. Our Vitalog digital monitor is fully programmable and in no way limited by the program described above. Any number of control programs could be written to record activity or illumination data differently and to monitor other functions through the unused A/D channels. These extended capabilities of the instrument can be utilized in our proposed 1981-1982 contract.

CONCLUSION

Mullaney, Kripke and Messin (9) have shown that a trained scorer can score wrist activity data for sleep/wake with accuracy approaching EEG scoring. In the present study, we have shown that wrist activity data can be digitized and scored automatically by computer with no loss in accuracy. Mullaney et al estimated that their activity scoring system was 5 to 10 times less costly than EEG scoring, and that the marginal decrease in accuracy was more than compensated by the greater amount of data that could be collected for a given expense. We feel that the automatic scoring system described here further improves the cost-benefit relationship by replacing the largely mechanical analog recording and playback system, including the polygraph, with an all-digital system. Automatic scoring is accomplished in seconds, eliminating the hours of skilled labor needed for writing out a polygraph record and the many minutes needed for visually scoring the record. Elimination of a scorer further reduces costs and for the first time makes the identification of sleep and wake fully objective, without the many opportunities for error and variability presented by human scoring. We are continuing with further algorithm refinements and testing, but it is unlikely much improvement can be obtained over the current results, nor is much improvement needed.

As of March, 1981, we have completed the major technical goals of our contract. Specifically, we have designed, built, tested, and evaluated a wearable digital activity monitor usable for sleep/wake scoring. Preliminary validation studies (using a retrospective technique) produced a $r=.9760$ correlation of automatic scoring of total sleep duration versus LEG scoring. This far exceeds our 90% design specification. Our technical development has been extremely successful. Judging from our experience with the same algorithm utilized with the laboratory computer, we believe there will be little or no degradation of validity in prospectively scored records, nevertheless, we are completing prospective validation in the remaining months of our 1980-1981 contract. In addition, we will submit an exact technical specification giving hardware and software specifications for a miniaturized microprocessor-controlled activity monitor. With this specification, a miniaturized monitor wearable entirely on the wrist could be designed and produced with currently available technology.

A miniaturized wrist-mounted sleep monitor could be used in field trials or in actual combat to monitor the fatigue and sleep-loss of Army troops.

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Figure 1. Schematic diagram of external activity transducer, photocell and level-matching amplification circuitry

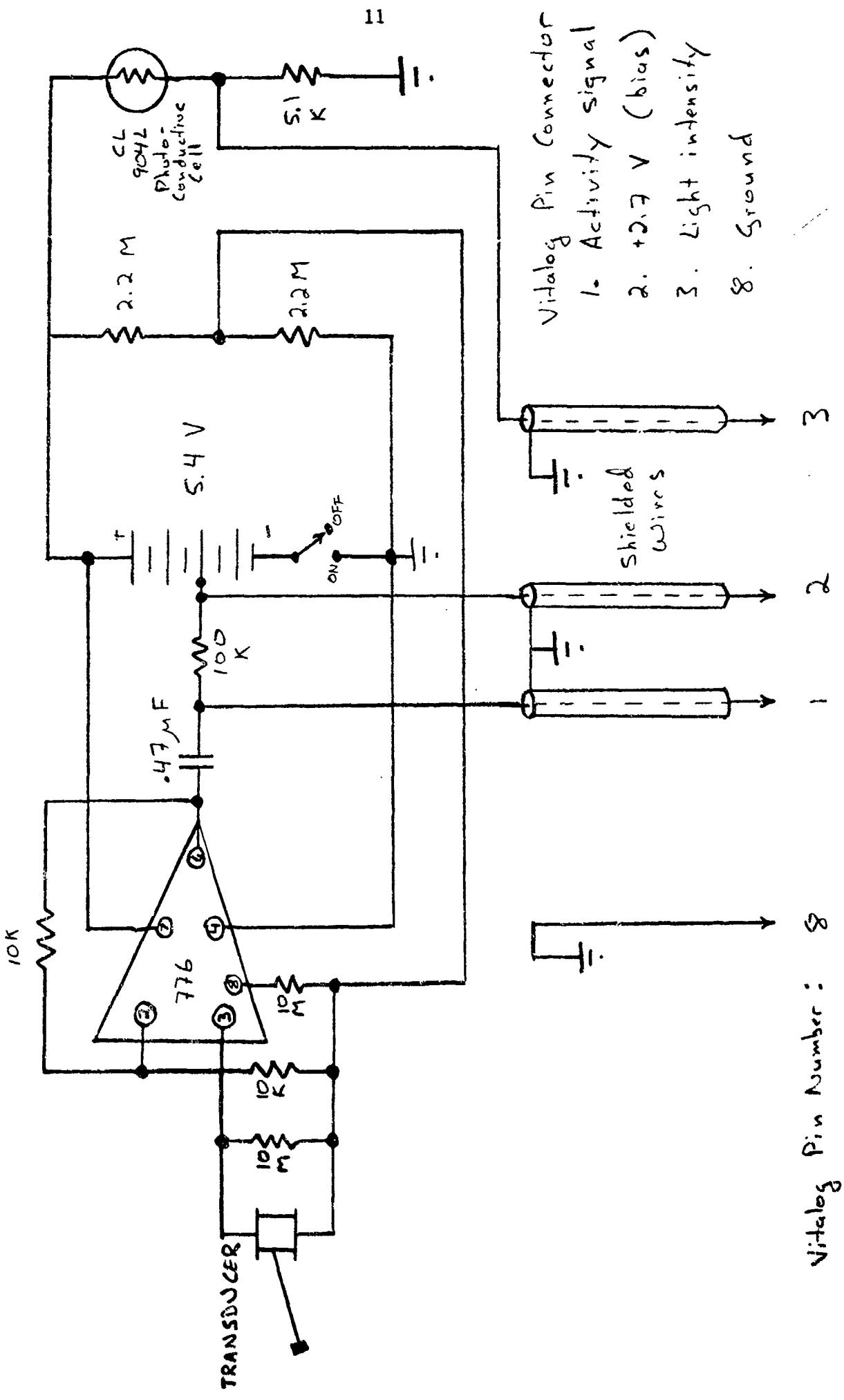


TABLE 1

Subject	Recording Duration (minutes)	% Agreement	% Sleep (EEG)	% Sleep (Act.)
1	353	97.17	0.00	2.83
2	574	96.17	45.47	46.86
3	632	95.89	56.80	59.65
4	903	83.82	29.57	34.33
5	660	97.42	54.55	56.21
6	798	95.36	41.73	44.11
7	845	96.80	37.99	40.95
8	1129	96.19	30.65	31.62
9	644	96.89	50.47	51.40
10	553	88.79	56.06	48.10
11	371	96.77	92.72	95.96
12	527	96.96	14.99	16.13
13	226	89.82	93.81	93.36
14	673	91.98	50.67	45.62
15	593	95.78	56.49	59.36
16	829	91.19	40.17	47.77
17	<u>692</u>	<u>94.08</u>	<u>15.17</u>	<u>20.18</u>
Total				
Retrospective	11002	94.46	42.09	43.98
18	369	93.50	70.19	76.69
19	846	93.62	28.84	31.68
20	<u>1271</u>	<u>98.35</u>	<u>36.82</u>	<u>37.69</u>
Total				
Prospective	2486	96.02	39.06	41.39

Table 1. Record duration, proportion of the record for which hand-scored EEG and automatically scored activity scores agree, and proportion of the record scored as sleep by the two techniques. Total duration and overall proportions for the records scored retrospectively and those scored prospectively are also presented.

TABLE 2

Subject	Recording Duration	% Agreement	% Sleep (EEG)	% Sleep (Act.)
1	366	89.92	85.71	95.80
2	2847	95.67	18.68	20.89
3	1472	97.95	24.27	25.91
4	2848	96.90	20.61	23.42
5	461	90.93	97.35	92.70
6	344	95.52	97.61	97.31
7	465	83.55	88.16	79.61
8	500	91.65	91.85	88.39
9	502	91.89	90.06	85.19
10	487	92.68	96.03	96.65
11	483	94.39	82.70	97.05
12	503	83.20	81.58	93.52
13	1100	92.12	35.47	39.32
14	487	90.17	89.33	98.33
<hr/>				
Total				
Retrospective	12739	93.61	46.38	48.87

Table 2. Record duration, proportion of the record for which hand-scored EEG and automatically scored activity scores agree, and proportion of the record scored as sleep by the two techniques. Total duration and overall proportions are also presented.

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 0035 C AUTHOR: JOHN WEBSTER
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 0037 C VA Medical Center - San Diego
 0038 C Mail Code V-116
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6653 GO TO 150
6654 110 IF (NA.NE.2HVI) GO TO 50
6655 FILE=2HVD
6656 LO=66
6657 LIM=65
6658 WRITE (LU1,125)
6659 125 FORMAT (1X, MULTPLY VITALOG SCORE BY:__)
6660 READ (LU1,*)
6661 XMULT
6662 LO=LO-XMULT*10
6663 LIM=LIM-XMULT*10
6664 150 WRITE (LU1,250)
6665 200 FORMAT (1X, NUMBER OF MINUTES FORWARD: --)
6666 READ (LU1,*)
6667 IFW
6668 KJ=IFW+1
6669 WRITE (LU1,250)
6670 250 FORMAT (1X, NUMBER OF MINUTES BACKWARD: --)
6671 READ (LU1,*)
6672 IFW=1B'J+IFW+1
6673 IF (IFW.LT.1H) GO TO 350
6674 WRITE (LU1,300)
6675 300 FORMAT (1X, 15 MINUTES MAX *** *)
6676 GO TO 150
6677 350 WRITE (LU1,400)
6678 400 FORMAT (1X, ENTER WEIGHTS FOR MINUTE. . .//)
6679 K=J
6680 DO 500 I=1BW,IFW
6681 K=K+1
6682 IF (I.GE.J) GO TO 480
6683 WRITE (LU1,470) K,I
6684 470 FORMAT (1X,12", I-12": --)
6685 GO TO 495
6686 480 IF (I.GT.J) GO TO 490
6687 WRITE (LU1,421) K
6688 490 FORMAT (1X,12", *I*: --)
6689 GO TO 495
6690 WRITE (LU1,491) K,I
6691 FORMAT (1X,12", I+11": --)
6692 491 READ (LU1,*)
6693 495 READ (LU1,*)
6694 500 CONTINUE
6695 NW(J)=J
6696 545 DO 550 I=1,4
6697 550 CONTINUE
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8127 875 DO 4233 10=101,126
8128 IF (HA.EQ.2HVI) GO TO 998
8129 IF (10.EQ.101) GO TO 4260
8130 IF (10.EQ.107) GO TO 4280
8131 IF (10.EQ.108) GO TO 4200
8132 IF (10.EQ.114) GO TO 4200
8133 IF (10.EQ.115) GO TO 4200
8134 IF (10.EQ.117) GO TO 4200
8135 GO TO 950
8136 IF (10.GE.115) GO TO 4200
8137 950 IFILE(3)=KCVT(10)
8138 C-----
8139 C READ DATA FILE
8140 C-----
8141 1000 CALL OPEN (IDCB,IER,IBUF,FILE)
8142 IF (IER.LT.0) GO TO 9960
8143 CALL READF (IDCB,IER,IBUF)
8144 IF (IER.LT.0) GO TO 9910
8145 LEN=IBUF*256+IBUF(2)
8146 IL=LEN+2
8147 CALL READF (IDCB,IER,IBUF,IL,JL,-1)
8148 IF (IER.LT.0) GO TO 9920
8149 IF (ILU(3).EQ.1) GO TO 2100
8150 WRITE (LUO,2999) IFILE,LEN
8151 2999 FORMAT (2H ,3A2,18 MINUTES--)
8152 C-----
8153 C PROCESS DATA
8154 C-----
8155 2100 DO 4999 I=3,IL
8156 DO 2200 J=1W,2,-1
8157 VECTR(J)=VECTR(J-1)
8158 ISTAT(J)=ISTAT(J-1)
8159 2200 CONTINUE
8160 ISTAT=1
8161 IF (HA.EQ.2HVI) GO TO 2380
8162 IF (IBUF(1).LE.0) IBUF(1)=63
8163 IF (IBUF(1).LT.-128) GO TO 2500
8164 IBUF(1)=IBUF(1)-123
8165 ISTAT=0
8166 VECTR=FLOAT(1IBUF(1))*XMULT
8167 IF (VECTR.GT.63) VECTR=63
8168 DO 3999 IZL=1,LN
8169 D=0.
8170 DOT=0.
8171 IF (I>2.LT.IW) GO TO 4999
8172 IF (IW>4).EQ.0) GO TO 3992
8173 CW(RW(4))=W(RW(4))*((IZL-1)/27-1)
8174 3992 IF (IW>3).EQ.0) GO TO 3994
8175 CW(RW(3))=W(RW(3))*((IZL-1).27)/9-1)
8176 3994 IF (IW>2).EQ.0) GO TO 3996
8177 CW(RW(2))=W(RW(2))*((IZL-1).9)/3-1)
8178 3996 IF (IW>1).EQ.0) GO TO 3998
8179 CW(RW(1))=W(RW(1))*((IZL-1).3)-1)
8180 3998 IW=0
8181 DO 3949 IZL=1,IW
8182 IW=IW+CW(IZL)
8183 3949 CONTINUE
8184 DO 3750 IZL=1,IW
8185 CW(IZL)=CW(IZL)/IW
8186 3750 CONTINUE
8187 C (DOT) PRODUCT LOOP
8188 2609 DO 2700 K=1,IW
8189 DOT=DOT*VECTR(K)*C(K)
8190 2700 CONTINUE

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C1191 DO 3330 JJ=LO,LIM
C1192 SCALE=JJ/1E3D.
C1193 0=DOT*SCALE
C1194 L=JJ-(LO-1)
C1195 KS=0
C1196 IF (0.GE.1.8) KS=2
C1197 LS=1STAT(KJ)
C1198 KLS=KS+LS+1
C1199 IPO(IZL,L,KLS)=IPO(IZL,L,KLS)+1
C1200 3862 CONTINUE
C1201 3903 CONTINUE
C1202 4062 CONTINUE
C1203 4206 CONTINUE
C1204 4330 NS=IPO(1,1,1)+IPO(1,1,3)+IPO(1,1,4)
C1205 NS=IPO(1,1,1)+IPO(1,1,2)+IPO(1,1,3)+IPO(1,1,4)
C1206 4379 DO 4799 J=1,LN
C1207 IMAX=G
C1208 IMAX=G
C1209 DO 4699 I=LO,LIM
C1210 L=1-(LO-1)
C1211 NC=IPO(J,L,1)+IPO(J,L,4)
C1212 IMAX=MAX(NIMAX,NC)
C1213 IF (NIMAX.NE.NC) GO TO 4518
C1214 SMAX=1/10000.
C1215 MAXJ=J
C1216 NMAX=MAX(NIMAX,NC)
C1217 IF (NMAX.NE.NC) GO TO 4699
C1218 MAXC=NC
C1219 SMAX=1/10000.
C1220 MAXI=L
C1221 46999 CONTINUE
C1222 IF (INW(4).EQ.8) GO TO 46992
C1223 CW(INW(4))=W(INW(4))+((J-1)/27-1)
C1224 46992 IF (INW(3).EQ.8) GO TO 46994
C1225 CW(INW(3))=W(INW(3))+((MOD((J-1),27)/9-1)
C1226 46994 IF (INW(2).EQ.8) GO TO 46995
C1227 CW(INW(2))=W(INW(2))+((MOD((J-1),9)/3-1)
C1228 46995 IF (INW(1).EQ.8) GO TO 46993
C1229 CW(INW(1))=W(INW(1))+((MOD((J-1),3)-1)
C1230 46993 WJ=J
C1231 DC 46995 I=1,10
C1232 WJ=JW+CW(1)
C1233 46995 CONTINUE
C1234 46995 I=1,10
C1235 CW(1)=CW(1)/MW
C1236 46995 CONTINUE
C1237 PC=100*FLOAT(NMAX)/FLOAT(NN)
C1238 IF ((LU((3)).EQ.1)) GO TO 4740
C1239 WRITE (LU(4900), (CW(I), I=1,10), SMAX, PC
C1240 46996 FORMAT (1H ,1.1F7.4,F7.2)
C1241 47999 CONTINUE
C1242 PS=100*FLOAT(NS)/FLOAT(NN)
C1243 PC=100*FLOAT(NMAX)/FLOAT(NN)
C1244 DO 48995 LM=1,4
C1245 PP(LM)=100*FLOAT(IPC(MAXJ,MAXI,LM))/FLOAT(NN)
C1246 49599 CONTINUE
C1247 IF ((LU(3)).EQ.1) GO TO 4950
C1248 WRITE (LU, 4043)
C1249 40439 FORMAT ('/')
C1250 WRITE (LU, 49399) PCC,MN,PS,(PP(I), I=1,4)
C1251 49399 FORMAT ('//', PERCENT, 'CORRECT: ', F6.2, '%')
C1252 //, MINUTES, SCORED: ', 15

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4255 IF ((NW(4).EQ.0)) GO TO 5002
4255 NW(4)=W(M(4))-W(M(4))+((MAXJ-1)/27)-1
4255 GO TO 5004
4257 IF ((NW(2).EQ.0)) GO TO 5004
4257 NW(2)=W(M(2))-W(M(2))+((MAXJ-1)/27)-1
4257 GO TO 5004
4259 IF ((NW(2).EQ.0)) GO TO 5004
4259 NW(2)=W(M(2))-W(M(2))+((MAXJ-1)/27)-1
4261 IF ((NW(1).EQ.0)) GO TO 5004
4261 NW(1)=W(M(1))-W(M(1))+((MAXJ-1)/3)-1
4263 WRITE (LU0,5010) (W(I), I=1,18),SSMAX,PCC
4263 5010 FORMAT (1H ,10F5.1,FG5.3,FG.2)
4264 IF ((LU(3).EQ.0)) GO TO 9053
4264 9053 IF (NW(1).EQ.0) GO TO 9040
4265 9040 I=1,4
4265 DO 9041 I=1,4
4266 IF (NW(1).EQ.0) GO TO 9040
4266 IF ((NW(1).EQ.0)) GO TO 9040
4267 IF ((NW(1).GT.1W) NW(1)=1
4267 9040 CONTINUE
4271 GO TO 620
4271 6205 WRITE (LUI,3689)
4272 3689 FORMAT (1H,MORE?: _)
4272 READ (LUI,8859) IANS
4272 8859 FORMAT (A2)
4276 IF (IANS.EQ.2)WE) GO TO 545
4277 9007 STOP 7777
4277 9007 STOP 7777
4278 9007 WRITE (LUI,9990) IER
4279 9279 STOP 1
4279 9279 WRITE (LUI,9990) IER
4281 9281 STOP 2
4282 9282 WRITE (LUI,9990) IER
4282 9282 STOP 2
4283 9283 FORMAT (1H,ERROR=16, **, *)
4284 9284 STOP
4285 9285 END
4285 9285 END

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0107	0000	MINUT.	0	MINUTE COUNT
0108	125	TCODE.	0	TIME CODE
0109	125	115.	-5	COUNTEP FOR TIME CODE
0110	150	CPSS.	0	
0111	151	CCHTP.	0	
0112	152	115.	-5	
0113	153	TCODE.	0	TIME CODE '0' OF '1'
0114	154	CODE1.	0	TIME CODE FLAG
0115	155	TFLOG.	0	
0116	155	115.	-30	MINUTE DIVIDER
0117	157	MINIV.	0	ACCUMULATES EPOCH SUM
0118	158	EPSSUM.	0	ACCUMULATES DIFSCP SUM
0119	141	DPSSUM.	0	
0120	142	1120.	-120	EPOCH DIVIDEP
0121	147	EP011V.	0	ACCUMULATES SUM TO 4
0122	144	SUM14.	0	
0123	145	114.	-4	ACCOUNTS 4
0124	146	CNT4.	0	MASK FOR DIFSCR
0125	147	1177.	177	
0126	150	11770.	770	HOLES DATA PRIOR TO STOP
0127	151	DATAFD.	0	POINTS TO TIME CODE PTN
0128	152	0600	0	CODET.
0129	153	0400	0	DIFSCP
0130	154	0000	0	PTEP
0131	155	1000	1000	CREATEP
0132	156	2001	1101	FLDI.
0133	157	7776	1121	PTN.L.1.
0134	160	7766	1122.	2001
0135	161	7600	1122.	-2
0136	162	4000	1122.	-10
0137	163	0000	1122.	7600
0138	164	0557	0	ACCPA TO WAIT
0139	165	0000	0	4000
0140	166	0000	0	HOLES MOST RECENT SUM
0141	167	0000	0	557
0142	170	0000	0	POINTS TO DIFSCP BUFFER
0143	171	0040	0	BUFFER LOC
0144	172	0000	0	
0145	173	0000	0	STORES
0146	174	2765	0	POINTS TO STORE PTN
0147	175	2770	0	
0148	176	2777	0	
0149	177	2077	0	
0151			0	
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0157			0	
0158			0	

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0215	31CS	EPOCH.	DCA	MINOT
0216	3146		DCA	EPSUM
0217	3141		DCA	DFSUM
0218	3142		TAD	M120
0219	3143		DCA	EPDIV
0220	3144		DCA	SUM1
0221	3145		TAD	M4
0222	3146		DCA	CNT4
0223	3147		TAD	TELAG
0224	3148		SZA	CLA
0225	4552		J15	CODETS
0226	274	6001	ION	ENTER EACH A/D
0227	275	7300	CLA	CLA
0228	276	1813	TAD	A13
0229	277	7841	CIA	
0230	308	1014	TAD	A14
0231	301	7440	SZA	/IS A/D BUFFEP EMPTY?
0232	302	5315	J1P	
0233	303	6504	PCFA	
0234	304	7421	NDL	
0235	305	7501	ND4	
0236	306	1162	TAD	0.4800
0237	307	6505	UCR4	
0238	310	7731	ACL	
0239	311	6505	UCP14	
0240	312	7000	NDP	
0241	317	7069	HOP	
0242	314	5275	J1P	ENTER
0243	315	7300	CLA	CLA
0244	316	1414	TAD	A14
0245	317	1145	TAD	SUM4
0246	318	3144	UCA	SUM4
0247	351	1014	TAD	A14
0248	342	1114	TAD	STEND
0249	323	7640	SZA	CLA
0250	324	5327	J1P	.43
0251	325	1111	TAD	STKREG
0252	326	2014	DCA	A14
0253	327	2146	IS2	SUM4
0254	328	5275	J1P	ND
0255	329	1144	TAD	SUM4
0256	322	4553	J15	1
0257	333	7100	CLL	DFSUM
0258	334	1141	TAD	ADD TO DIFSUM
		7430	S2L	
		535	STA	TRUNCATE IF TOO LARGE
		536	DCA	/IS IT AN EPOCH YET?
		547	IS2	
		2140	EPDIV	
		2143	J1P	
		5266	FOUP	
		341	DFSUM	
		1141	TAD	
		7110	CLL	
		7041	CIA	
		1104	TAD	

0268	347	5253	44	NO
0270	350	1141	DFSM1	YES, REPLACE OLD
0271	351	7116	CLL FAP	
0272	352	3104	MAXEP	
0273	353	2157	FC4	
0274	354	5262	152	IS IT A MINUTE YET?
0275	355	0002	JIP	NO
0276	356	1363	10F	YES, PEARLITE LEVEL
0277	357	4866	THJ	AF01 A/V, CH.2
0278	360	3151	J15	
0279	361	0001	JCQ	
0280	362	5267	104	
0281	363	0002	JIP	
0282	364	7000	HOP	
0283	365	7000	HOP	
0284	366	7000	HOP	
0285	367	4571	STOP	
0286	368	7302	HLT	
0287	369	1104	MAXP	
0288	370	3151	TAB	
0289	371	3151	DATAPD	
0290	372	4571	STOP	
0291	373	7402	HLT	
0292	374	5242	HIP	
0293	375		HIP	
0294	376		HIP	
0295	377		HIP	
0296	378		HIP	
0297	379		HIP	
0298	380		HIP	
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0300	382		HIP	
0301	383		HIP	
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0304	386		HIP	
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0317	399		HIP	
0318	400		HIP	
0319	401		HIP	

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0377	461	2165	LNXI.	152
0378	462	5240	JIP	JIP
0379	463	7100	CLL	MINLO
0380	464	1540	TAD	CIA
0381	465	7041	CIA	MINLO
0382	466	3540	DCA	MINLO
0383	467	7439	SCL	
0384	468	7091	IAC	MINHI
0385	469	1541	TAD	CIA
0386	470	7041	CIA	MINHI
0387	471	1541	DCA	MINHI
0388	472	7041	IAC	MINHI
0389	473	3341	DCA	MINHI
0390	474	7100	CLL	PPNLO
0391	475	1342	TAD	MINLO
0392	476	1340	TAD	PRDLO
0393	477	3342	DCA	SCL
0394	478	500	IAC	PRDHI
0395	479	7430	TAD	MINHI
0396	480	1343	TAD	PRDHI
0397	481	501	IAC	PRDHI
0398	482	7001	TAD	BUFLOC
0399	483	1343	TAD	BUFLOC
0400	484	503	IAC	A16
0401	485	7430	TAD	BUFLOC
0402	486	1343	TAD	BUFLOC
0403	487	503	IAC	A15
0404	488	7430	TAD	BUFLOC
0405	489	1343	TAD	BUFLOC
0406	490	503	IAC	A15
0407	491	7430	TAD	BUFLOC
0408	492	1343	TAD	BUFLOC
0409	493	503	IAC	A16
0410	494	7430	TAD	BUFLOC
0411	495	1343	TAD	BUFLOC
0412	496	503	IAC	A15
0413	497	7430	TAD	BUFLOC
0414	498	1343	TAD	BUFLOC
0415	499	503	IAC	A16
0416	500	7430	TAD	BUFLOC
0417	501	1343	TAD	BUFLOC
0418	502	503	IAC	A15
0419	503	7430	TAD	BUFLOC
0420	504	1343	TAD	BUFLOC
0421	505	503	IAC	A16
0422	506	7430	TAD	BUFLOC
0423	507	1343	TAD	BUFLOC
0424	508	503	IAC	A16
0425	509	7430	TAD	BUFLOC
0426	510	1343	TAD	BUFLOC
0427	511	503	IAC	A16
0428	512	7430	TAD	BUFLOC
0429	513	1343	TAD	BUFLOC
0430	514	503	IAC	A16
0431	515	7430	TAD	BUFLOC
0432	516	1343	TAD	BUFLOC
0433	517	503	IAC	A16
0434	518	7430	TAD	BUFLOC
0435	519	1343	TAD	BUFLOC
0436	520	503	IAC	A16
0437	521	7430	TAD	BUFLOC
0438	522	1343	TAD	BUFLOC
0439	523	503	IAC	A16
0440	524	7430	TAD	BUFLOC
0441	525	1343	TAD	BUFLOC
0442	526	503	IAC	A16
0443	527	7430	TAD	BUFLOC
0444	528	1343	TAD	BUFLOC
0445	529	503	IAC	A16
0446	530	7430	TAD	BUFLOC
0447	531	1343	TAD	BUFLOC
0448	532	503	IAC	A16
0449	533	7430	TAD	BUFLOC
0450	534	1343	TAD	BUFLOC
0451	535	503	IAC	A16
0452	536	7430	TAD	BUFLOC
0453	537	1343	TAD	BUFLOC
0454	538	503	IAC	A16
0455	539	7430	TAD	BUFLOC
0456	540	1343	TAD	BUFLOC
0457	541	503	IAC	A16
0458	542	7430	TAD	BUFLOC
0459	543	1343	TAD	BUFLOC
0460	544	503	IAC	A16
0461	545	7430	TAD	BUFLOC
0462	546	1343	TAD	BUFLOC
0463	547	503	IAC	A16
0464	548	7430	TAD	BUFLOC
0465	549	1343	TAD	BUFLOC
0466	550	503	IAC	A16
0467	551	7430	TAD	BUFLOC
0468	552	1343	TAD	BUFLOC
0469	553	503	IAC	A16
0470	554	7430	TAD	BUFLOC
0471	555	1343	TAD	BUFLOC
0472	556	503	IAC	A16
0473	557	7430	TAD	BUFLOC
0474	558	1343	TAD	BUFLOC
0475	559	503	IAC	A16
0476	560	7430	TAD	BUFLOC
0477	561	1343	TAD	BUFLOC
0478	562	503	IAC	A16
0479	563	7430	TAD	BUFLOC
0480	564	1343	TAD	BUFLOC
0481	565	503	IAC	A16
0482	566	7430	TAD	BUFLOC
0483	567	1343	TAD	BUFLOC
0484	568	503	IAC	A16
0485	569	7430	TAD	BUFLOC
0486	570	1343	TAD	BUFLOC
0487	571	503	IAC	A16
0488	572	7430	TAD	BUFLOC
0489	573	1343	TAD	BUFLOC
0490	574	503	IAC	A16
0491	575	7430	TAD	BUFLOC
0492	576	1343	TAD	BUFLOC
0493	577	503	IAC	A16
0494	578	7430	TAD	BUFLOC
0495	579	1343	TAD	BUFLOC
0496	580	503	IAC	A16
0497	581	7430	TAD	BUFLOC
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0499	583	503	IAC	A16
0500	584	7430	TAD	BUFLOC
0501	585	1343	TAD	BUFLOC
0502	586	503	IAC	A16
0503	587	7430	TAD	BUFLOC
0504	588	1343	TAD	BUFLOC
0505	589	503	IAC	A16
0506	590	7430	TAD	BUFLOC
0507	591	1343	TAD	BUFLOC
0508	592	503	IAC	A16
0509	593	7430	TAD	BUFLOC
0510	594	1343	TAD	BUFLOC
0511	595	503	IAC	A16
0512	596	7430	TAD	BUFLOC
0513	597	1343	TAD	BUFLOC
0514	598	503	IAC	A16
0515	599	7430	TAD	BUFLOC
0516	600	1343	TAD	BUFLOC
0517	601	503	IAC	A16
0518	602	7430	TAD	BUFLOC
0519	603	1343	TAD	BUFLOC
0520	604	503	IAC	A16
0521	605	7430	TAD	BUFLOC
0522	606	1343	TAD	BUFLOC
0523	607	503	IAC	A16
0524	608	7430	TAD	BUFLOC
0525	609	1343	TAD	BUFLOC
0526	610	503	IAC	A16
0527	611	7430	TAD	BUFLOC
0528	612	1343	TAD	BUFLOC
0529	613	503	IAC	A16
0530	614	7430	TAD	BUFLOC
0531	615	1343	TAD	BUFLOC
0532	616	503	IAC	A16
0533	617	7430	TAD	BUFLOC
0534	618	1343	TAD	BUFLOC
0535	619	503	IAC	A16
0536	620	7430	TAD	BUFLOC
0537	621	1343	TAD	BUFLOC
0538	622	503	IAC	A16
0539	623	7430	TAD	BUFLOC
0540	624	1343	TAD	BUFLOC
0541	625	503	IAC	A16
0542	626	7430	TAD	BUFLOC
0543	627	1343	TAD	BUFLOC
0544	628	503	IAC	A16
0545	629	7430	TAD	BUFLOC
0546	630	1343	TAD	BUFLOC
0547	631	503	IAC	A16
0548	632	7430	TAD	BUFLOC
0549	633	1343	TAD	BUFLOC
0550	634	503	IAC	A16
0551	635	7430	TAD	BUFLOC
0552	636	1343	TAD	BUFLOC
0553	637	503	IAC	A16
0554	638	7430	TAD	BUFLOC
0555	639	1343	TAD	BUFLOC
0556	640	503	IAC	A16
0557	641	7430	TAD	BUFLOC
0558	642	1343	TAD	BUFLOC
0559	643	503	IAC	A16
0560	644	7430	TAD	BUFLOC
0561	645	1343	TAD	BUFLOC
0562	646	503	IAC	A16
0563	647	7430	TAD	BUFLOC
0564	648	1343	TAD	BUFLOC
0565	649	503	IAC	A16
0566	650	7430	TAD	BUFLOC
0567	651	1343	TAD	BUFLOC
0568	652	503	IAC	A16
0569	653	7430	TAD	BUFLOC
0570	654	1343	TAD	BUFLOC
0571	655	503	IAC	A16
0572	656	7430	TAD	BUFLOC
0573	657	1343	TAD	BUFLOC
0574	658	503	IAC	A16
0575	659	7430	TAD	BUFLOC
0576	660	1343	TAD	BUFLOC
0577	661	503	IAC	A16
0578	662	7430	TAD	BUFLOC
0579	663	1343	TAD	BUFLOC
0580	664	503	IAC	A16
0581	665	7430	TAD	BUFLOC
0582	666	1343	TAD	BUFLOC
0583	667	503	IAC	A16
0584	668	7430	TAD	BUFLOC
0585	669	1343	TAD	BUFLOC
0586	670	503	IAC	A16
0587	671	7430	TAD	BUFLOC
0588	672	1343	TAD	BUFLOC
0589	673	503	IAC	A16
0590	674	7430	TAD	BUFLOC
0591	675	1343	TAD	BUFLOC
0592	676	503	IAC	A16
0593	677	7430	TAD	BUFLOC
0594	678	1343	TAD	BUFLOC
0595	679	503	IAC	A16
0596	680	7430	TAD	BUFLOC
0597	681	1343	TAD	BUFLOC
0598	682	503	IAC	A16
0599	683	7430	TAD	BUFLOC
0600	684	1343	TAD	BUFLOC
0601	685	503	IAC	A16
0602	686	7430	TAD	BUFLOC
0603	687	1343	TAD	BUFLOC
0604	688	503	IAC	A16
0605	689	7430	TAD	BUFLOC
0606	690	1343	TAD	BUFLOC
0607	691	503	IAC	A16
0608	692</			

SUF-F.	
0.431	551
0.432	552
0.433	553
0.434	554
0.435	555
0.436	556
0.437	557
0.438	558
0.439	559
0.440	560
0.441	561
0.442	562
0.443	563
0.444	564
0.445	565
0.446	566
0.447	567
0.448	570
0.449	571
0.450	572

0539	652	22.40	ISZ	STORES	NO, RETURN +1
0540	653	5640	JMP	STORES	YES, WHICH FLD?
0541	654	1124	TAD	FLDFLG	
0542	655	7440	SZA		
0543	656	5640	JMP	STORES	FLD 1, RTRN & END
0544	657	2124	ISZ	FLDFLG	FLD 0, SWITCH TO FLD 1
0545	670	7240	STA		
0546	671	3017	DCA	DATA[P	RESET DATA PTR TO TOP
0547	672	22.40	ISZ	STORES	
0548	673	5640	JMP	STORES	RTRN +1
0549	0550				
0551					
0552					
0553					
0554					
0555					
0556					
0557					
0558					
0559					
0560					
0561					
0562					
0563					

*RECORDED MEMORY
 MAXIMAL EPOCH ACTIVITY SCORE AND
 LUTT LEVEL FOR EACH MINUTE ARE
 STORED IN ALTEPIATE MEMORY LOC'S
 #F011 LOC. 700 TO 5777 (FLD 0)
 #A91000 TO 15777 (FLD 1)
 *700
 \$66

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